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ESTIMATING DAMAGE CAUSED BY ROOT DISEASES IN
FORESTED AREAS

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Preface

This guide is intended for forest pathologists and forest land managers who are interested in estimating damage caused by root diseases in forested areas. It is also a catalogue of the types of root disease surveys performed by Forest Pest Management pathologists in the Pacific Northwest. As forest resources become more valuable, it is imperative that accurate estimates be made of the current and potential damage caused by root diseases. Also, because of the insidious nature of root diseases, special techniques are needed to detect and estimate the damage they cause.

There are some limitations to this guide. It is not intended to serve as a manual to identify or describe forest root diseases or discuss their control measures. Also, the purpose of this guide is not to discuss in detail forest sampling techniques and statistics; references to appropriate literature are provided. Even though the survey methods discussed in this guide are intended for estimating damage caused by forest root diseases, other pests that cause similar damage may be surveyed likewise, and indeed such pests may be associated intimately with root diseases.

I. Damage Caused by Root Diseases

A tree becomes infected with one or more root pathogens and with time this infection may be manifested in some form of symptom or damage. Several factors determine whether or not infection will cause visible damage and how rapidly this occurs: tree species, age, vigor, and genetics; pathogen species and genetics; and site and environmental conditions. In estimating damage caused by root diseases, three types of damage are encountered most commonly: (a) root and butt decays, (b) tree mortality, and (c) tree growth loss.

A. Root and Butt Decays

Damage caused by many root pathogens occurs as an internal root and butt decay. Although direct tree mortality or growth loss can occur, loss may only be wood decay as a result of infection. Tree mortality may occur indirectly as a result of infected trees being windthrown or broken due to decayed roots or excessive butt decay. Root and butt decays often are associated with severe butt wounds or sporophores. Root and butt decays are difficult to assess and usually require some form of internal tree sampling to detect.

B. Tree Mortality

Many root pathogens directly cause tree mortality. Whether a pathogen does cause mortality and how rapidly this occurs again depends on the aforementioned characteristics of the tree, the pathogen, and their environment. Tree mortality is the easiest type of damage to assess, and oftentimes infected trees will show advanced symptoms such as thin, chlorotic crowns before they die.

C. Tree Growth Loss

Although not well studied, several root pathogens may cause loss in tree growth before a tree is killed. Growth loss is the most difficult type of damage to detect and estimate. At the very least, it requires some form of internal tree sampling and is only precise if the tree is felled and annual ring patterns studied at several points along the stem. Also, in order to make accurate comparisons between infected and non-infected trees, total excavation of root systems is necessary. A more detailed explanation of methods to measure tree growth loss due to root diseases is treated elsewhere (Thies 1981, Bloomberg^{et al.} 1980).

II. Individual Tree Examinations

To properly estimate damage caused by root diseases in forested areas, it is necessary to examine individual trees to determine whether or not they are infected and to what degree. There are four methods that can be used to examine individual trees, two being relatively non-destructive such as root collar exams or internal tree exams and two requiring tree destruction through felling or total root excavation.

A. Root collar Exams

Although root disease often can be detected by observing above-ground damage, there are several other agents such as insects, animals, or environmental factors that cause similar symptoms. It then becomes necessary to perform a root collar exam at the very minimum to positively identify damage

caused by root diseases. Root collar exams require some sort of digging implement, the pulaski being the best choice. Soil is removed from the top of one or more main lateral roots near the root collar to examine for external signs of root pathogens such as sporophores or ectotrophic mycelium. Root bark is then removed to look for internal signs of pathogens such as mycelial fans. Lastly, root wood is chopped to examine for sapwood stains or heartwood stains and decays. Wood fragments may be collected and cultured to positively identify species of root pathogens.

B. Internal Exams

When root pathogens cause root and butt decays, it may be necessary to perform an internal examination to detect root diseases. In some cases where stain or decay extends into major lateral roots, such damage may be detected by root collar exams. In many cases, however, stain and decay are confined to the butt or deeper roots.

The simplest and least destructive method to detect internal decays is by drilling with a portable battery-powered drill with thin (1/16-3/32 inch diameter) bits. Extensive internal decay or hollows can be detected readily as the root collar is drilled and a change in torque occurs. Although stain and early stages of decay cannot be detected with the drill alone, it is possible to use a Shigometer or similar instrument to accurately measure the degree of stain or decay (Shigo and ^{Berry} Shigo 1974⁵).

Internal exams also can be made with an increment borer. Increment boring requires more work and is more destructive than drilling, but the degree of stain or decay can be assessed from the extracted core. Also, it is possible to culture suspected root pathogens from the core (Cordell and Stambaugh 1966). Increment cores also can be used to estimate tree growth loss by comparing growth rings from healthy and diseased trees.

A third method to detect internal stains and decays is by drilling with a gasoline-powered drill with a 1/2 in. or larger diameter bit to extract wood chips from the root collar for culturing of suspected root pathogens (Blair and Driver 1977). The chip extraction method is more accurate than either root collar exams or increment boring to detect trees infected by root pathogens (Schmitt 1978).

C. Tree Felling

A more accurate estimate of the presence of root pathogens in a tree can be obtained by examining the freshly cut surface of felled trees. Also, to measure the extent of internal stains or decays or to accurately estimate tree growth loss due to root diseases, trees must be felled. The tree is felled usually with a chainsaw as close to the ground as possible.

To measure the volume of stain or decay in a tree, the stem is sectioned every 1 or 2 feet until the stain or decay is no longer evident. The cross-sectional area of the stain or decay at the cut surface of the first and last stem section is measured, and volume is calculated using Smalian's Formula: $V = (\frac{a+b}{2})L$

where V = volume

a = cross-sectional area of first stem section

b = cross-sectional area of last stem section

L = total length of all stem sections

An easy way to measure the cross-sectional area of stain or decay is to photograph each cut surface in the forest and measure the cross-sectional area from the photo with a planimeter or digitizer in the office (Thies and Harvey 1979). If only decay is to be measured (stain may not be considered damage), then only stem sections with decay are measured. In sections where both stain and decay are present, the decay is outlined with a felt pen, photographed, and measured.

Tree felling is a necessity if accurate measurements of tree growth loss are to be estimated, especially height growth loss. One-half to one inch thick disks are cut from various points along the stem. Disks usually are removed at DBH, top of the first merchantable log and at the top merchantable diameter in order to calculate volume growth loss. Too much butt swell with some tree species, especially older trees, may result in inaccurate measurement from disks cut at the stump. Growth rings over a specific period of time are measured across two or three randomly chosen radii on each disk to obtain average growth rate. Height growth loss is estimated by measuring leaders

back for a specific number of years. In both cases, it is necessary to know whether or not a tree is infected to compare growth and estimate loss, and to be accurate, this requires total root excavation.

D. Total Root Excavation

Excavation of entire root systems is the most accurate method of determining whether or not a tree is infected by root pathogens. It is also the most expensive, time consuming, and environmentally damaging. Several methods can be used to excavate root systems. Small trees simply can be pulled out of the ground by hand to expose root systems. Larger trees require heavy machinery such as backhoes or bulldozers to excavate root systems. In some cases, pushing over the intact tree to gain leverage may be easier than pushing out the stump after a tree has been felled (Roth et al 1977). Light charges of explosives such as Tovex may be used to loosen the stump and remove most of the soil to examine root systems (Miller and Partridge 1973).

III. Methods for Surveying Diseased Areas

Except for very small areas, it is not necessary nor practical to examine every tree for root diseases. Instead, areas are sampled by examining trees on only a portion of the entire area and expanding the resulting data to represent the total area. Damage caused by root diseases can be surveyed and expressed in two ways: (a) on a per acre basis or (b) as actual diseased land area.

A. Per Acre Methods

Damage caused by root diseases often is expressed on a tree per acre, basal area per acre, or volume per acre basis. Damage expressed in this manner usually is infected tree mortality, but live-infected trees, trees with root and butt decay, and even trees with growth loss may be expressed on a per acre basis.

There are two sampling methods that can be used to estimate damage on a per acre basis; establishment of fixed-area plots or establishment of variable radius plots. A more detailed explanation of their use in forest sampling is presented elsewhere (Avery 1967, Dilworth 1974).

1. Fixed-Area Plots

Fixed-area plots have definite boundaries of known dimension and usually are circular or square in shape or established as strips across the area to be surveyed. Usually, all trees within fixed-area plots are examined for damage caused by root diseases. However, only one or more trees in a plot may be sampled randomly if more than a root collar exam is performed such as drilling or felling. DBH and height of each tree are measured if basal area and volume data are desired. Form class which is used to calculate volumes must be obtained if local volume tables are unavailable. Per acre data for the entire area are obtained by expanding the plot count (number of trees, total basal area, total volume) by the appropriate factor.

Size of fixed-area plots is dependent on the ^{disease intensity} stocking density of the area surveyed. ^{severely diseased} Densely stocked areas need smaller plots than ^{lightly} sparsely stocked areas. Usually 1/10 acre or 1/5 acre plots are established. Fixed-area plots can be used for sampling areas with any size of tree.

2. Variable-Radius Plots

Variable-radius plots have no definite boundary; plot boundaries are determined by using a prism. Variable-radius plots are used to sample larger diameter trees, usually greater than 5 inches DBH. The appropriate basal area factor (BAF) of the prism is selected so that 5 to 7 trees are tallied with each plot. As with fixed-area plots, usually all plot trees are examined for damage caused by root diseases, but only one or more trees may be subsampled if more than a root collar exam is performed (Goheen et al 1980).

DBH and height are recorded if trees per acre and volume per acre data are desired. Basal area per acre is obtained simply by dividing the total number of trees within all plots by the number of plots and multiplying

by the BAF. Trees per acre are obtained by dividing the total number of trees within all plots by the number of plots and multiplying by a stand table factor based on average tree DBH for the area (Dilworth 1974). Volume per acre is calculated by multiplying trees per acre by the volume for the average tree DBH class for the area. Usually total volume per acre is obtained by calculating the trees per acre for each DBH class within the area, multiplying each by the volume for that size class, and adding the resulting figures.

Although more variable-radius plots than fixed-area plots are required to obtain the same degree of accuracy, the time to establish variable-radius plots is much less than the time required to establish fixed-area plots. Thus, less time is spent establishing more variable-radius plots than fixed-area plots to obtain the same degree of accuracy.

The optimum crew size for surveying with either fixed-area plots or variable-radius plots is three: one person to establish plot boundaries and record data and two people to measure diameters and heights and make root collar exams. Two people may suffice if height data are not taken.

3. Two Simultaneous Plots

Often it is desirable to obtain damage information on all size classes of trees. In this case, variable-radius plots defined by two prisms of different BAF but with the same center can be used. A larger prism (40 to 80 BAF) is used to define larger diameter trees and a smaller prism (10 to 20 BAF) is used to define smaller diameter trees (Gregg 19--). If data are needed on trees less than 1 inch at DBH as well as data on larger trees, both a fixed-area plot and a variable-radius plot can be established simultaneously ^{where} ~~when~~ both plots have the same center. Trees greater than or equal to 5 inches DBH are tallied on variable-radius plots and all trees less than 5 inches DBH are tallied on fixed-area plots. Per acre data are calculated separately for each type of plot.

4. Number and Arrangement of Plots

Theoretically, the optimum number of plots (and their size for fixed-area plots) is dependent on the variability of the parameter being measured; in this case, the incidence of damage. This requires prior knowledge

of damage extent. Since damage extent often is not known--that's the reason why we are doing the survey--the number and arrangement of plots often is based on the size of the area to be surveyed.

Generally, some form of systematic sampling scheme, usually a systematic grid, is used rather than a random sampling procedure. Small areas of 50 acres or less usually are sampled using plots located on a 2x2 chain or 2x5 chain grid. This assures complete coverage of the area with enough plots to minimize sampling error. Larger areas of 50 to 400 acres may be surveyed using a 5x5 chain or 5x10 chain grid. On areas over 400 acres, a 10x10 chain grid may be used (Filip 1977). Areas over 500 acres should be divided into smaller units no larger than 500 acres to minimize transect lengths. If possible, large areas may be stratified into homogenous units such as stand types or age classes and each unit surveyed separately.

In large areas where damage caused by root disease is infrequent and a 10x10, 5x10, or even a 5x5 chain grid is used, damage can be missed entirely. In this case, intermediate plots (count plots) are established between regular plots (measure plots) as each transect is followed. A 10x10 chain grid then becomes a 5x10 chain grid or a 2x10 chain grid. Usually there is too much overlapping when plots are established closer than two chains. Data are collected on count plots only when a diseased tree is present within the plot; otherwise, the plot is recorded as healthy and no measurements are taken. If a diseased tree is present, data are collected on diseased trees only. It is not necessary to collect data on healthy trees in diseased plots, since sufficient data on healthy trees are collected in measure plots. Data on diseased trees in count plots are combined with data on diseased trees in measure plots to obtain per acre figures. Establishment of count plots along transects requires very little time since the area is visited anyway. With this method, time spent examining healthy trees is minimized, while time spent examining diseased trees is maximized.

5. Data Usage

The use of variable-radius plots and/or fixed-area plots to estimate damage caused by root diseases enables one to compare incidence of damage between (1) tree species, (2) tree size/age classes, (3) root diseases, or any

other categories where information is collected. Often it is desirable that forest managers know whether root diseases (and which ones) are affecting only one tree species or size/age class. This may have implications for disease management, since some tree species may be disease-tolerant or perhaps only a certain size/age class is being affected. Also, per acre data can be used by forest managers in a form they normally use--a per acre basis.

Often it is desirable to construct root disease distribution maps for a survey area. Circles can be used to depict location of plots. Diseased plots can be shaded while healthy plots are left clear. Diseased plots can be designated further by type of root disease. Also, it may be more meaningful to designate for each plot the percent of trees, basal area, or volume diseased (Filip et al 1980). This is particularly easy to do for percent basal area that is diseased if variable-radius plots are established. The number of healthy and diseased trees designated by the prism is directly proportional to their basal area. For fixed-area plots, percent of diseased trees per plot is obtained easily by simple tree count.

B. Diseased Land Area Methods

For certain situations, it may be desirable to express damage caused by root diseases on an infected area basis. The problem lies in defining what is "infected area." Theoretically, infected area is land area that covers infected root material. This is difficult to ascertain since soil is not transparent, therefore total root excavation is needed to accurately determine whether root systems are infected or not.

It is much easier to express infected area based on above-ground tree symptoms such as tree mortality or advanced crown symptoms. However, mortality and advanced crown symptoms are crude estimators of infected area since roots can be infected without trees showing above-ground symptoms (Filip 1980). Often "area-out-of-production" or "diseased land area" which covers the rooting area of dead and visibly affected trees is used instead of infected area to express damage. In areas where root disease creates distinct centers or pockets, such as in stands composed primarily of one tree species, it is easy to estimate area out-of-production, since diseased areas are well defined.

Table 1 Relationship between tree diameter (DBH) and rooting zone

Rooting zone		Rooting zone		Rooting zone	
<u>DBH (in)</u>	<u>radius (ft)</u>	<u>DBH (in)</u>	<u>radius (ft)</u>	<u>DBH (in)</u>	<u>radius (ft)</u>
1.0	2.7	10.0	8.8	19.0	14.9
2.0	3.4	11.0	9.5	20.0	15.6
3.0	4.0	12.0	10.2	21.0	16.3
4.0	4.7	13.0	10.8	22.0	16.5
5.0	5.4	14.0	11.5	23.0	17.6
6.0	6.1	15.0	12.2	24.0	18.3
7.0	6.8	16.0	12.9	25.0	19.0
8.0	7.4	17.0	13.6	25+	19.0
9.0	8.1	18.0	14.2		

In areas where there are more than one tree species that show different degrees of susceptibility, disease pockets may not be well defined. Also, in mature stands, salvage logging may have destroyed the integrity of disease pockets after dead and dying trees were harvested. In both cases, it may be necessary to define diseased area on a tree-by-tree basis. Diseased area is then defined as that area surrounding each dead or symptomatic tree that covers the roots of that tree. It assumes that 100% of the roots are infected. Rooting area roughly is equivalent to crown cross-sectional area projected to the ground. Since crown cross-sectional area is proportional to DBH (Krajicek et al 1961), rooting area can be estimated from DBH (Table 1). This relationship varies by stocking density of the stand (the more dense the stand, the smaller the rooting area), by tree species, and by site and soil conditions. Rooting area tables can be modified for local conditions if more accurate data are available.

There are several methods that can be used to estimate diseased area: establishment of (1) fixed-area plots, (2) variable-radius plots, (3) line intercept method, and (4) aerial photography.

1. Fixed-Area plots

Fixed-area plots, as described earlier, can be used to estimate diseased area by estimating the area of each plot that is diseased--contains roots of diseased trees--and expanding this figure based on the size and number of plots. Fixed-area plots usually are circular or square in shape or established as strips across the area to be surveyed.

a. Circular or Square Plots

Circular or square plots can be established by partially flagging plot boundaries or corners as a reference. If no diseased trees are present within or adjacent to the plot, the plot is recorded as non-diseased and no measurements are taken. If one or more diseased trees are within or adjacent to the plot, DBH of each diseased tree is measured and the rooting area of each tree is extracted from the table and recorded on the data sheet.

If only part of the rooting area falls within the plot, then the percent of the rooting area within the plot is estimated and recorded. If a diseased tree lies outside the plot, but part of its rooting area falls within the plot, then the percent of the rooting area within the plot is estimated and recorded. It is generally faster to record DBH and percent of rooting area within the plot, and calculate diseased area later in the office.

Cause of the disease is determined by root collar or other exam and recorded with the other figures. All diseased trees with rooting areas falling within the plot are recorded. It is possible to record infected stumps from harvested trees; however, stumps may have become infected after trees were harvested. Some provision must be made for rooting area overlap, since plots cannot contain more damaged area than total plot area. *but this is still diseased area*

A crew of three is most efficient; one person to record data and two people to establish plot boundaries and examine and measure trees.

b. Strip Plots

Strip plots are established as continuous strips of definite width (usually one-half to one chain) across the entire length of the area to be surveyed. Strips are followed until a diseased tree is found within or adjacent to the strip, in which case DBH of the diseased tree is measured, the percent of rooting area within the plot is recorded, and the cause of the disease is determined. When there is considerable rooting area overlap, the entire width of the strip may be recorded as diseased.

A crew of three is most efficient; two persons to walk the boundaries of the strip, measure trees, and make root collar exams, while a third person records data and keeps the other two people on strip boundaries.

2. Variable-Radius Plots

It is possible to estimate the proportion of diseased area by using variable-radius plots. Basal area per acre of diseased trees divided by

the total basal area per acre usually is slightly below the actual proportion of diseased area and may be multiplied by 1.5 to derive the actual proportion of diseased area.

3. Line-Intercept Method

With the line-intercept method (Bloomberg^{et al} 1980), diseased area is estimated by walking transects of known length across areas to be surveyed. The lengths of transects that fall within diseased areas is recorded. The sum of the lengths of diseased transects divided by the total transect length estimates the proportion of land area that is diseased.

The line-intercept method is used most frequently where distinct disease centers exist (Goheen et al 1980). The length of transect between the point one enters the disease center and the point one exits, the center is measured and recorded. Usually, some sort of tape such as a chain tape is dragged as transects are followed to measure lengths of diseased transects.

assumes centers are circular

In diseased areas devoid of distinct pockets, the individual tree measurement can be used. The length of transect that falls within the diseased rooting zone is measured. Three people can accomplish this most effectively. One person drags the tape and records data. Two people follow the tallyman and search for diseased trees that are within 19 feet of the tape (the radius of the largest rooting area, Table 1). When a diseased tree is detected, DBH is measured and the rooting area radius is obtained from the table (tallyman). By using some sort of tape measure (a retractable logger's tape works best), the tape is extracted the length of the rooting area radius. One end is placed on the diseased tree; the other end is fully extended to the dragged tape, and the number on the dragged tape where the tapes intersect is recorded (near intercept). A second reading is taken on the dragged tape on the other side of the diseased tree in a similar fashion (for intercept). Where several diseased trees are adjacent to one another so that their rooting areas overlap, the near intercept is recorded for the first tree encountered and the far intercept is recorded for the last tree encountered.

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As diseased lengths are measured, cause of the disease is determined by root collar or other exams. Since all measurements are definite, almost no estimations need be made as with fixed-area plots.

4. Number and Arrangement of Plots

As discussed earlier, the optimum number of plots (and with fixed-area plots, their size) is dependent on the variability of the parameters being measured. Since prior knowledge of accurate damage incidence is rarely known, the number and arrangement of plots are based on size of the area to be surveyed.

Small areas of 50 acres or less can be surveyed by establishing plots (circular, square, or variable-radius) on a 2x2 chain or 2x5 chain grid. Transects for the line-intercept method or strip plots can be established 5 chains apart. Large areas of 50 to 400 acres may be surveyed on a 5x5 or 5x10 chain grid for circular, square, or variable-radius plots. Transects or strip plots can be established every 5 chains. For areas over 400 acres, a 10x10 chain grid may be used for circular, square, or variable-radius plots, while transects or strips can be established every 10 chains. Areas larger than 500 acres should be stratified into smaller units. If disease is infrequent, intermediate plots may need to be established.

5. Aerial Photographs

Use of large-scale (1:4000 or 1:6000) color infrared aerial photographs to estimate area damaged by root pathogens has been used successfully in certain timber types, particularly stands that show distinct disease centers (Williams and Leaphart 1978, Gregg et al 1978). Smaller scale (1:31680) black and white photographs have been used to measure diseased areas where pockets are large (100 feet or more in diameter) and distinct (Johnson and Wear 1975).

Areas to be surveyed are 100 percent photographed vertically. With a stereoscope, diseased areas are identified on photographs as openings in the canopy containing dead and dying trees on the margins and with snags, windthrown trees, some dead trees, and some living trees in the centers. Diseased areas are delineated on the photographs with ink. A random sample of these diseased areas are visited on the ground to determine their cause and identify root pathogens if present. Areas delineated on photographs are measured with a planimeter or similar device. The areas contained in disease

centers divided by the total area are an estimate of the proportion of diseased area. A sample of the areas with dead trees not delineated or caused by root disease also should be examined on the ground to check for errors of omission. It may be possible to use aerial photography to measure damage on a trees per acre basis if individual dead and symptomatic trees can be detected on the photographs.

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6. Data Usage

Damage expressed as diseased land area can be used in a variety of ways. If figures for normal trees per acre, basal area per acre, or volume per acre are known for a particular area, it is possible to multiply the percent of diseased area by these figures to obtain damage expressed on a per acre basis. These figures are thus as reliable as the normal per acre figures.

Damage expressed as diseased land area requires less time to collect than per acre data. Thus, damage can be estimated very rapidly over very large areas. Also, if stands are composed of primarily one tree species and are affected primarily by one root disease, per acre data can be obtained much faster by measuring diseased land area if normal per acre figures are known.

IV. Special Situations

A. Plantations and Orchards

Potential damage caused by root diseases in proposed plantations and orchards can be estimated by examining the native trees before and immediately after felling. Small areas may be surveyed in total, but larger areas usually are sampled systematically with either fixed-area plots or variable-radius plots.

Crown symptoms and root collar symptoms can be used to detect 50-60% of all infected trees in an area (Filip 1981). Examination of freshly cut stump surfaces for stain and decay will improve detection to about 75% of the infected trees.

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6. Comparison of Methods to Estimate Diseased Land Area

Four methods to estimate diseased land area were tested in the field to compare (1) accuracy in estimating diseased land area and (2) performance time.

Circular plots, strip plots, variable-radius plots, and line-intercept method were tested on six 50-acre blocks infected by root diseases in two geographical areas.

Each method was performed as described earlier by a crew of three. In addition, each 50-acre block was 40 percent surveyed to serve as a standard to compare accuracy of the four methods.

Results are displayed in Tables ²~~3~~ and ~~4~~. Of four methods tested, circular plots were the most accurate in estimating diseased land area, however the method took the longest to complete. Line-intercept method was nearly as accurate and took almost half the time of the circular-plot method to complete. Although the variable-plot method was the least accurate in estimating diseased land area, the per acre data obtained while using this method may offset the loss in accuracy in estimating diseased land area.

Damage caused by root diseases in established plantations and orchards can be estimated with fixed-area plots for small diameter trees--usually less than 5 inches DBH (Johnson and Thompson 1976)—or with variable-radius plots for larger trees. Root collar exams may be all that is necessary, but where practical, total root excavations will be more accurate.

If the number of plantations or orchards to examine is large or terrain and brush make ground surveying difficult, another technique used to estimate damage is the helicopter survey. Where recently-killed or dying trees appear red or yellow and contrast sharply with healthy green trees, it is possible to make accurate counts of damage (trees per acre) from the air (Filip 1979).

Helicopters are better than fixed-winged aircraft for surveying plantations and orchards because helicopters can fly slower and hover. A crew of two plus the pilot can estimate damage in several plantations in hours that would take ground crews days to complete. As the helicopter travels along the border of the plantation with a tallyman to the inside of the plantation, the tallyman counts all recently killed and dying trees. Dead trees without needles (old mortality) may be difficult to detect from the air and are best estimated from a sample ground survey. The second crew member preferably should know the terrain so that he can direct the pilot from one plantation to the next.

All plantations (or a sample if there are many) that are surveyed aerially are examined on the ground to (1) aid in detecting old mortality and (2) determine causal agents of mortality. The purpose of the ground examination need not be to confirm figures from the aerial survey, since in most cases the aerial count will be the most accurate.

The ground examination may be as a fixed-area plot (1/10 to 1/5 acre) established in an area of concentrated tree mortality within the plantation. All trees within the plot are tallied by crown condition and cause of mortality through either a root collar exam or total root excavation if trees are small. Old mortality for the entire plantation is calculated by multiplying recent mortality figures (counted from the air) by the ratio between old mortality and recent mortality (counted in fixed-area plots). Total mortality is the

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Table 1 Acres Diseased (out of 50) and Time (hours) to Complete Each Survey

Survey Method	Sisters Blocks			Tieton Blocks			Average
Percent of Area Sampled	One	Two	Three	One	Two	Three	
Check Survey	8.15 ^a	22.50	20.05	7.25	3.65	2.35	10.65
(40%)	5.2 ^b	10.1	22.0	5.2	5.4	5.8	9.0
Strip Plot	12.35	16.80	22.05	10.50	3.25	2.85	11.30
(8.9%)	2.6	8.8	11.5	2.8	2.2	2.9	5.1
Circular Plot	10.25	16.70	19.35	10.80	3.80	1.80	10.45
(8.0%)	3.2	7.5	11.9	4.6	2.6	2.5	5.4
Variable Plot	8.35	11.10	17.70	6.15	4.25	3.20	7.25
	4.9	4.2	5.1	4.6	4.3	4.5	4.6
Line- Intercept	7.80	20.65	20.55	6.45	3.55	2.85	10.30
	2.1	3.7	3.5	3.3	2.7	1.7	2.8

^a Acres

^b Hours

sum of recent mortality and old mortality. Damage expressed as trees per acre is easy to calculate since the size of the plantation generally is known.

B. Developed Recreation Sites

Individual trees in developed recreation sites take on special significance. Each tree has aesthetic value but also has the potential for causing human or property damage if it fails. Since most trees in developed recreation sites fail at the roots, it is important to make accurate estimates of the damage caused by root diseases (Filip and Goheen 1981).

Most developed recreation sites can be surveyed in their entirety. However, in very large developments this is tedious because of the large number of trees involved. Large areas can be stratified first, based on level of human occupancy. High occupancy zones are examined first and low occupancy zones are surveyed as time permits (Hadfield and Filip 1981). Large areas also can be stratified based on disease presence. Units with diseased trees are surveyed very intensely, while those with no dead or dying trees receive only a cursory inspection (Filip 1980). Large areas also can be sampled with fixed-area plots or variable-radius plots to estimate damage caused by root disease, especially for proposed sites (Filip and Goheen 1981).

When examining individual trees, some sort of drilling either with an electric drill or increment borer should be performed to detect root and butt decays in suspected trees--those with large, old wounds or sporophores (Hadfield and Filip 1981). It is important to know the diameter of soundwood in infected trees to determine potential for windthrow or stem breakage.

C. Large Acreage

For areas over 5,000 acres, it may be impractical to estimate damage caused by root diseases using the methods already described, especially ground surveys. Plots arranged on larger grids may be an alternative. National Forest inventory in the Pacific Northwest Region and the survey unit of the Pacific Northwest Range and Experiment Station use a systematic grid of 1.7 and 3.4 miles square, respectively, with a 10-point variable-radius plot cluster at each plot to survey forest resources on a Forest-wide or State-wide basis (USDA Forest Service 1980).

Large areas may be stratified by timber types that are more susceptible to damage caused by root diseases. For instance, in the Pacific Northwest, damage caused by root diseases is more prevalent in the Douglas-fir or true fir timber types. Concentrating survey efforts in these stands would increase efficiency.

Where aerial photography can be used to detect root diseases, a survey system using double sampling with regression may be appropriate (Wear et al 1966). A grid size is established based on parameter variability or size of survey area. The entire plot is photographed vertically from an aircraft. Plot size can vary from one acre in very dense stands to 40 acres in very open stands.

Photos are scanned with a stereoscope and root-diseased areas are identified (as previously discussed) and outlined in ink. Areas delineated on photographs are measured with a planimeter or similar device. The areas contained within disease plots divided by the total plot area is an estimate of diseased plot area (X_1).

A random sample of diseased plots is visited on the ground. Some sort of sampling system--variable-radius plots, fixed-area plots, or line intercept--is used to estimate diseased area (Y_2) and identify causal agents.

An estimate of total diseased area is derived from the photo plots and the ground plots by the following formula: $\bar{Y}_1 = \bar{Y}_2 + b(\bar{X}_1 - \bar{X}_2)$

where: $\bar{Y}_1$ = ave. diseased area for entire area (percent or acreage)

$\bar{Y}_2$ = ave. diseased area from ground plots

b = regression coefficient

$\bar{X}_1$ = ave. diseased area from all photo plots

$\bar{X}_2$ = ave. diseased area from sampled photo plots only

Some healthy-appearing plots also should be examined on the ground to determine errors of omission. They can be surveyed similar to diseased plots.

It may be possible to use trees per acre that are diseased (dead or symptomatic) instead of or with diseased area, if diseased trees can be detected on aerial photographs.

A Word of Caution

No matter how small a tract of land may be, there are no easy methods to estimate damage caused by root diseases in forested areas. Soil is not transparent, and trees can't tell us where they hurt. Surveys using root collar exams, internal exams, felling, or root excavations require more time than normal stand cruising procedures. More importantly, the key in making accurate estimations of damage lay in the surveyor's ability to (1) differentiate root diseases from agents causing similar damage and (2) identify root pathogens causing the disease. Disease management for a particular area is dependent on the accuracy of the survey, and errors in identification of root diseases can lead to gross mismanagement with ramifications far into the future. Root disease surveys should be performed only by individuals who have had the training and experience in identification of forest root diseases. The intent here is not to discourage root disease surveys in damaged areas; on the contrary, Forest Pest Management pathologists encourage and are willing to perform any survey described in this guide at the request of land managers.

The following are examples of forested areas with damage caused by root diseases and suggested survey methods that can be used to estimate damage.

Case 1:

Size: 75 acres
Timber type: Mixed species with various degrees of susceptibility (MIXED)
Age/Size Class: uneven aged/several diameter classes (UNEVEN)
Mortality Estimate: 10-25%
Survey Method: 2x5 chain grid, variable-radius plots, all measured.

Case 2:

Size: 530 acres
Timber Type: MIXED
Age/Size Class: UNEVEN
Mortality Estimate: 25-50%
Survey Method: 10x10 chain grid, variable-radius plots, all measured.

Case 3:

Size: 230 acres
Timber Type: Single species
Age/Size Class: 10-20 years old, ave. DBH < 5 inches
Mortality Estimate: 10-25%
Survey Method: (1) 5x5 chain grid, fixed-area plots (1/10 acre circular) or
(2) helicopter count with ground sampling.

Case 4:

Size: 940 acres
Timber Type: MIXED
Age/Size Class: UNEVEN
Mortality Estimate: 1-10%
Survey Method: Divide into two smaller units or stratify by stands if possible; 2x10 chain grid, variable-radius plots; measure every fifth plot, count others.

Case 5:

Size: 850 acres
Timber Type: Single species
Age/Size Class: 90 years old, ave. DBH >10 inches
Mortality Estimate: 10-25%
Survey Method: Divide into two smaller units;
(1) Line intercept with lines 10 chains apart or
(2) 5x10 chain grid, variable radius plots, all measured.

Case 6:

Size: 10,500 acres
Timber Type: MIXED
Size/Age Class: UNEVEN
Mortality Estimate: 1-10%
Survey Method: Double-sampling with regression; 250 photo plots each 1-10 acres; randomly select 50 diseased plots and 10 healthy plots to ground survey; ground survey using 2x5 chain grid, variable-radius plots, all measured.

Case 7:

Size: 150 acre (campground)
Timber Type: MIXED
Size/Age Class: 350 years old, ave. DBH >20 inches
Mortality Estimate: 1-10%
Survey Method: Stratify by occupancy zones; 100% survey high occupancy zones; drill suspected trees.

Case 8:

Size: 175 acres
Timber Type: MIXED
Size/Age Class: UNEVEN
Mortality Estimate: 1-5%
Survey Method: 2x5 chain grid, variable-radius plots; measure every other plot, count others.

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Case 9:

Size: 2,500 acres

Timber Type: Single species

Size/Age Class: UNEVEN

Mortality Estimate: 10-25%

Survey Method: (1) Aerially photograph entire area at 1:4000 or 1:6000
using color IR film; ground check random sample of
areas delineated on photographs or
(2) subdivide into 5 units or stratify by age classes;
line-intercept method, 10-chain interval between tran-
sects.

Case 10:

Size: 5,700 acres

Timber Type: MIXED

Size/Age Class: UNEVEN

Mortality Estimate: 1-10%

Survey Method: (1) Aerially photograph entire area at 1:4000 or 1:6000
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